Texture and other Physicochemical Properties of Whole Rice Bread

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ABSTRACT: Samples of experimental rice breads baked in a home bread machine were evaluated by physicochemical methods and compared with a local commercial whole-wheat bread. The results showed that rice breads had less specific volume, harder texture, and were more prone to retrogradation during storage than whole wheat bread. All stored breads showed a peak at about 52 °C by differential scanning calorimetry (DSC) analysis, which is characteristic of retrograded starch. However, the ΔH for rice bread was about 3 times the value of whole-wheat bread, suggesting its strong tendency to retrograde. X-ray diffraction (XRD) evaluation also indicated the appearance of a strong 2θ peak between 16.7 °C to 17.0 °C in rice bread than in whole-wheat bread, which is consistent with starch retrogradation.

Keywords: rice bread, retrogradation, texture profile analysis, differential scanning calorimetry, x-ray diffraction, bran

Introduction

RICE IS AN IMPORTANT FOOD GRAIN. IT has many unique attributes, such as ease of digestion, bland taste, and hypoallergenic properties. However, rice has relatively low amounts of proteins and most of them are very hydrophobic and therefore resist swelling in water at neutral pH (Juliano 1985; Lumdubwong and Seib 2000). Rice proteins are also devoid of the elastic plastic properties that are indigenous characteristics of wheat gluten (gliadin + glutenin), essential for making bread and other baked goods (Juliano 1985). The low protein contents and absence of gliadin moiety in rice proteins, however, make it an ideal food material to feed patients suffering from celiac sprue (gluten-sensitivity disease), other chronic diarrhea diseases, and conditions needing low-protein diets (Hartsook 1984).

Bread and other baked food products are among the most widely used consumer food items in the world. For a long time, it was not possible to make acceptable yeast-leavened, bread-like products using rice flour, even though some progress had been made in developing gluten-free bread (Kulp and others 1974). Nishita and others (1976) developed a yeast-leavened rice-bread formula using hydroxypropyl methylcelluloses (HPMC) as a substitute for gluten during proofing. In subsequent work, Nishita and Bean (1979) showed that rice varieties having low amylose contents and low gelatinization temperatures gave superior crumb properties. In a survey of celiac patients and hospital dietary personnel, the need was identified to improve the quality of available gluten-free yeast bread, so that it might more closely resemble conventional whole wheat bread than the available products (Ylimaki and others 1989). Recent availability of household bread machines has made it possible to easily custom bake novel breads at home. Rice bread made with a recommended recipe (Hall 1996) in a home breadmaker (WS 0598, Williams-Sonoma, Inc., San Francisco, Calif., U.S.A.) yielded a crumbly, dry, fluffy, but poor-flavored bread. Adding small amounts of defatted bran improved both texture and flavor. The final baked bread was in many respects comparable to whole-wheat bread. However, the bread still tended to retrograde and become crumbly within a few days during storage at refrigerated (4 °C) temperature. Earlier rice breads (Nishita and others 1976) were also reported to have a very short shelf-life. Little information is available about the extent of retrogradation in rice breads as measured by differential scanning calorimetry (DSC), X-ray diffraction (XRD), and texture profile analysis (TPA). The specific objectives of this study were to compare the textual and physicochemical characteristics of improved whole rice bread with a locally and commercially available popular whole-wheat bread (Nature's Own®), and to evaluate the need for additional research.

Materials and Methods

Whole rice bread

Mixtures of white rice flour, milled defatted bran (Riceland Foods Inc., Stuttgart, Ark., U.S.A.), salt, sugar, yeast (Fleischmann's bread machine yeast, Fenton, Mo., U.S.A.), rice bran oil (Riceland Foods Inc.), HPMC (Methocel K4M, Dow Chemical Co., Midland, Mich., U.S.A.) and deionized water (234.5, 23.5, 6.0, 30.0, 7.0,14.0, 7.0 and 265.0 g, respectively) were mixed as follows: The dry ingredients were mixed in a blender. A water/rice bran/oil mixture was heated to about 42 °C to melt the oil completely. The dry mix and oil-water mixture were put into the baking pan of the bread machine. The mixture was kneaded manually for 10 min at 43 °C and the "custom" program started. The mixture was allowed to rise for 40 min, followed by 2 min of punching and leveling the dough. The procedure was repeated 2 more times and the dough was baked for 35 min at 235 °C. For comparison purposes, a fresh whole-wheat bread was obtained from a local grocery store.

The baked whole rice bread was weighed and the loaf's volume determined by the rapeseed displacement method (Nishita and others 1976). The bread was cut into 2 halves. One half was wrapped in a plastic bag and stored in the refrigerator at 4 °C. The other half was sliced into 1- cm-thick slices, comparable to freshly baked commercial whole-wheat bread. An aliquot portion of the sliced whole rice or wheat bread was evaluated by an informal panel of judges for eating quality, texture, appearance, and also by using a texture analyzer (Model TA-XT2; Texture Technologies Corp., Scarsdale, N.Y., U.S.A.). The moisture of the sliced bread was determined with an official method (American Association of Cereal Chemists, Inc. 1995). Another aliquot of sliced whole rice or wheat bread was dried, using the method of Kim and others (1997) by suspending the broken pieces in absolute alcohol. The DSC and XRD analyses, as described below, were conducted on the dried material. The same evaluations were repeated after 1 w on the bread samples stored at the refrigerator temperature.

Table 1—Moisture and specific volume of breads.

	Moisture Day 1	Weight (g) Day 1	Volume (mL) Day 1	Sp Vol (mL/g) Day 1
100% Long grain (LG)	51.2	522.4	968.5	1.9
90% Long grain (LG)-10% Short grain (SG)	50.9	521.7	951.0	1.8
Whole-wheat bread	44.9	661.5	3520.0	5.3

Texture profile analysis

The TPA analysis was conducted on fresh and on 1-w-old refrigerated bread samples by using a TA-XT2 texture analyzer, using a 25-mm circular probe. One cm of the edges of the bread samples was removed from all sides. Then approximately a 10 × 23-mm piece was punched out, placed on the flat stage, and the texture determined. The texture analyzer settings were as follows: pre-test speed, 2 mm/s; post-test speed, 1 mm/s; rupture test distance, 1%; distance 30% strain; force, 0.10 kg; time, 1.0 s; (auto) trigger force, 0.020 kg and contact area 230 mm^2. The above procedure was repeated for each determination. Real-time data acquisition was accomplished by following the TA-XT2's User Guide (Anonymous 1997). The software was used to calculate hardness (kg), fracturability (kg), springiness, cohesiveness, chewiness, and resilience values of the bread samples (Bourne 1982). The TPA values reported are the averages of 3 different determinations.

Differential scanning calorimetry (DSC)

DSC of the dried bread samples was carried out using a Hart Scientific Model 4100 differential scanning calorimeter (Calorimetry Sciences Co., Spanish Fork, Utah, U.S.A.). The calorimeter was equipped with 4 cylindrical 1-mL Hastelloy ampules. One of the ampules was used as a reference cell and was filled with deionized water. The weight of water added was equal to the weight of sample plus water added in dried bread samples. The dried bread samples had about 11 to 12% moisture. The 3 remaining ampules were used for DSC analysis of dried bread samples. The dried bread samples (0.25 g) were weighed directly into the ampules and deionized water (0.50 g) was added to each ampule. The ampules were agitated and weighed again. The 4 sealed ampules were heated from 30 °C to 150 °C, cooled to 30 °C, and then reheated and cooled in the same manner. The heating and cooling rate was 60 °C/h. The DSC program performs point-to- point integration to calculate ΔH. The initial onset (T_o), peak (T_p) and completion temperatures (T_c) were measured from the graph. The enthalpy (ΔH) was expressed as cal/g of dried bread sample by integration of the thermal curves by using the software provided by Calorimetry Sciences Co. The values reported are the average of 2 separate determinations.

X-ray diffraction

Ethyl alcohol-extracted, room-temperature-dried bread samples (Kim and others 1997) were ground in a mortar with pestle to less than 149-µm particle size to obtain uniform homogeneous samples. Samples of about 0.7 g were pressed into 10 × 25-mm pellets with a hydraulic press (2300 kg). The pellets were mounted at the center of the goniometer circle and XRD data were obtained using a Rigaku Model D-Max B x-ray diffractometer (Rigaku/USA, Inc., Danvers, Mass., U.S.A.). The instrument was equipped with a water-cooled rotating copper anode that produced Cµ K*a* x-rays with an accelerating voltage of 40 kV and a tube current of 50 mA. The goniometer, equipped with a photo multiplier detector, scanned an angular range (2θ) between 8° and 28° at a scan rate of 0.5°/min. The values reported are the average of 3 replicates of each sample.

Results and Discussion

Several rice bread formulas have been reported in the literature. Nishita and Bean (1979) recommended the use of low-amylose and low-gelatinization-temperature rice flour for making good rice bread, even though long-grain rice was also occasionally found to have desirable baking characteristics. Hall (1996) mentioned only rice (white) flour without any specification about its amylose content or gelatinization temperatures. Kadan and others (1997) evaluated several leading U.S.-grown rice cultivars to make rice fries and found that, in spite of its high amylose (21.5%) and protein contents (8.2%), Cypress long-grain (LG) cultivar produced better textured fries than some other cultivars having low amylose contents. Our laboratory also has extensive information about Cypress LG cultivar's proximate composition and related physicochemical properties (Kadan and others 1997; 2001). Therefore, LG white rice flour was used to make rice bread. Using published formulations, preliminary evaluation of rice bread and LG rice flour (Nishita and others 1976; Hall 1996) yielded specific volumes (data not shown) of about 5 mL/g. However, they were crumbly, dry, and had poor (bland) flavor. These characteristics were considered undesirable in a survey of celiac patients and hospital dietary personnel (Ylimaki and others 1989). Incorporation into the bread mix in small amounts of defatted stabilized rice bran (about 10% by weight of rice flour) (Hargrove 1990) significantly improved the flavor and appearance. Informal taste-panel evaluation indicated that the final baked bread had several of the desirable characteristics of whole-wheat bread. The whole-rice bread was moist, and the undesirable dry, crumbly texture was absent. However, the rice bread lost its softness and became inelastic within a day or so. The replacement of 10% LG with a short-grain (SG) NFD 108 cultivar improved the dry texture, and it took longer to develop a dry texture.

The moisture and specific volume of the experimental rice bread loaves and a commercial whole-wheat bread are given in Table 1. The rice breads have higher moisture and lower specific volume than the whole-wheat bread, indicating the escape of gases during proofing and the baking process. Incorporation of 23.5-g rice bran also necessitated adding additional water in excess of that in the published formulas (Nishita and others 1976; Hall 1996), as it added about 7-g dietary fiber (mostly water-insoluble) and about 3.8-g protein, additionally (Hargrove 1990). Rice bran fiber is, however, very hydrophilic and can absorb almost its weight

Table 2—Texture profile analysis of experimental rice breads and whole wheat bread.

	100% Long grain		90% Long grain -10% Short grain		Whole wheat	
	First Day	Seventh Day	First Day	Seventh Day	First Day	Seventh Day
Hardness (kg)	0.40 ±[1]0.04	1.49 ± 0.07	0.24 ± 0.02	1.22 ± 0.15	0.04 ± 0.00	0.09 ± 0.03
Fracturability (kg)	0.40 ± 0.04	1.49 ± 0.07	0.24 ± 0.02	1.22 ± 0.15	0.04 ± 0.00	0.09 ± 0.03
Springiness	1.82 ± 0.36	0.62 ± 0.06	2.18 ± 0.37	0.64 ± 0.01	1.07 ± 0.02	1.31 ± 0.52
Cohesiveness	0.8 ± 0.01	0.35 ± 0.05	0.81 ± 0.01	0.26 ± 0.05	0.39 ± 0.00	0.69 ± 0.26
Gumminess	0.32 ± 0.03	0.50 ± 0.10	0.20 ± 0.01	0.32 ± 0.07	0.01 ± 0.00	0.06 ± 0.03
Chewiness	0.58 ± 0.10	0.32 ± 0.07	0.44 ± 0.07	0.20 ± 0.05	0.02 ± 0.00	0.08 ± 0.04
Resilience	0.48 ± 0.02	0.18 ± 0.04	0.48 ± 0.01	0.14 ± 0.02	1.83 ± 0.06	0.28 ± 0.60

[1]± ≈ Standard deviation

of water. On the other hand, rice proteins are mostly hydrophobic and resist swelling in water (Lumdubwong and Seib 2000). The additional rice fiber and proteins from rice bran therefore probably interfered with the gas retention ability of methocel (HPMC), thus resulting in a substantial decrease in the loaf volume. Replacement of a part of LG with 10% SG imparted a more desirable softer texture, but did not increase the specific volume. Consequently, there is a need to further explore other polysaccharides (Haque and others 1994) and additives which might enable rice bread to retain more gases during processing. The lower specific volume of rice bread, as compared to either whole-wheat bread or bread without added bran, may not be objectionable. It would be more realistic to regard whole-rice bread as a different bread product with which to satisfy the unique needs of consumers requiring a special diet (Hartsook 1984). Incorporation of rice bran does impart several whole-wheat-bread-like properties, including improved flavor, and it adds significant amounts of desirable nutrients (Hargrove 1990). Nevertheless needed is identification of additives and related processing techniques which can further increase the specific volume, as well as improve the overall acceptance of rice bread.

The TPA values of rice breads in contrast to the whole-wheat bread are given in Table 2. It can be seen that all TPA values of experimental rice breads, except resilience, are much higher than those for whole-wheat bread. Resilience is the ability of a material to return to its original shape after a stress. The resilience values decreased substantially after 1-w storage at refrigerated temperature in all 3 bread samples, but the final values were still about twice that in whole-wheat bread than in rice breads. The hardness and fracturability values for LG rice bread were 10 times higher than for whole-wheat bread. The replacement of LG with 10% SG decreased both hardness and fracturability values in fresh breads, but increased nearly 10 times after 1-w storage. The springiness, cohesiveness, and chewiness values decreased in rice breads but increased in whole-wheat bread after 1-w storage, indicating that rice bread became more brittle than whole-wheat bread and probably unsuitable for making sandwiches. Little prior information is available about the TPA values of rice bread, as previous researchers had primarily used hedonic rating to evaluate experimental breads (Haque and Morris 1994). Substantial increase in hardness and decrease in resilience values of all 3 breads during storage for 7 d at refrigerated temperature suggested the onset of starch retrogradation. The DSC and XRD data discussed below clearly confirmed pronounced starch retrogradation in rice breads.

The DSC thermograms of the fresh and 1-w-old breads are shown in Figure 1 and the DSC characteristics of materials in Table 3. The original LG and SG used in the rice breads had a T_p of 78.7 and 78.2 °C, respectively (data not shown). The thermograms of the 2 fresh rice breads showed that both rice starches are completely gelatinized during the baking process. During storage, however, both rice breads with either all LG or a mixture of LG and SG devel-

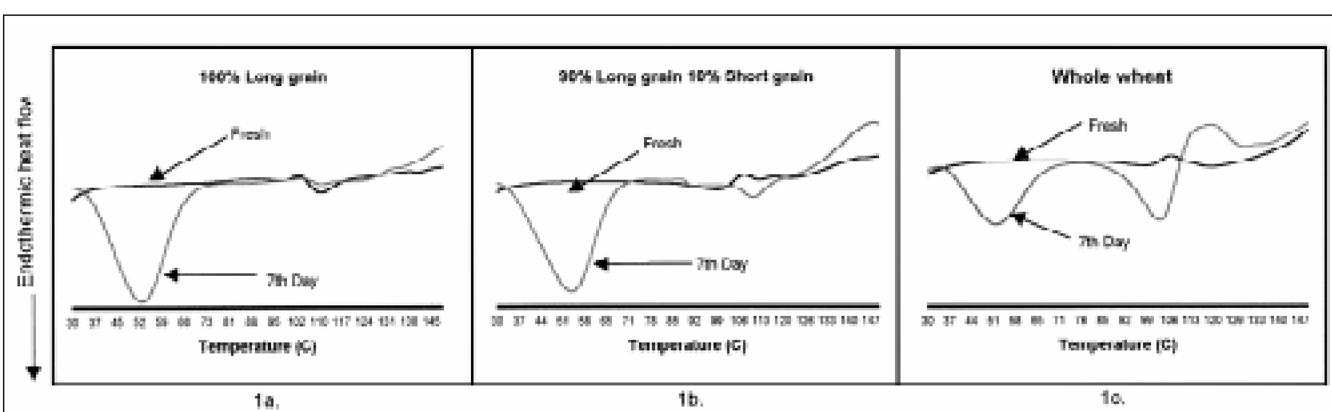

Figure 1–DSC thermograms of retrograded rice breads and whole wheat bread.

Table 3—DSC characteristics of retrograded breads (100% long grain, 90% long grain+10 % sweet, and whole wheat bread).

	Peak 1				Peak 2			
Composition	Init.temp (T_o) °C	Peak temp (T_p) °C	Final temp (T_c) °C	ΔH cal/g	Init.temp (T_o) °C	Peak temp (T_p) °C	Final temp (T_c) °C	ΔH cal/g
100% Long grain LG)	31.0	52.3	76.7	1.5105.9	111.6	118.1	slight[1]	
90% Long grain (LG)+10% Short grain (SG)	31.0	54.4	80.0	1.4	103.0	111.2	119.2	0.1
Whole wheat	33.5	51.7	77.0	0.579.0	102.7	115.5	0.6	

[1]≈ 0.01

Table 4—Distribution of peak intensities for baked 100% long grain, wheat bread, and 90% long grain with 10% short grain.

2 Θ =	12.8°	16.7°–17.0°	19.5°
100% Long grain	755 ±[1]15	–	1102 ± 55
100% Long grain day 7	755 ± 45	967 ± 34	992 ± 47
90% Long grain-10% Short grain	706 ± 63	–	-1158 ± 6
90% Long grain-10% short grain day	7615 ± 57	833 ± 61	853 ± 53
Whole wheat	654 ± 02	806 ± 04	915 ± 8
Whole wheat day 7	720 ± 12	850 ± 01	1043 ± 0

[1]± ≈ Standard deviation

oped new enthalpy peaks at T_p 52.3 and 54.4 °C, respectively. The appearance of these peaks coincided with a substantial increase in hardness and decrease in springiness and resilience TPA values, which are considered characteristics of starch retrogradation in bread (Zobel and Senti 1959). No previous studies describing the DSC thermograms of rice breads were found in the literature. However, Kim and others (1997) studied the DSC thermograms of retrograded rice starch gels and reported peaks (T_p) at 56 and 57 °C from waxy and non-waxy rice flours, respectively. Surprisingly, even the whole-wheat bread (which may have different kinds of Dstarch than rice bread) developed a peak in the same vicinity as the rice breads during storage. There was an additional peak in 1-w-old whole-wheat bread at T_p of 102.7 °C (ΔH 0.6 cal/g). There are slight and comparable peaks at about 111 °C in rice breads. These 3 peaks are probably formed by the starch, sugar and lipid complexes during retrogradation (Biliaderis and others 1985). The enthalpy peaks (Table 3) indicated that retrograded 100% LG rice bread had the highest ΔH (1.5 cal/g), followed by rice bread in which part of LG was replaced by 10 % SG (ΔH 1.4 cal/g) whereas whole-wheat bread had the lowest ΔH (only 0.5 cal/g). Rice breads are known to have a relatively short shelf-life (Nishita and others 1976). Rice flour breads are also less responsive to dough conditioners and shortening than wheat breads (Nishita and others 1976). The reasons for these differences are not obvious. One possible explanation may be the hydrophobic nature of rice proteins (Lumdubwong and Seib 2000) as compared to the known hydrophilic nature of wheat gluten. Dough conditioners have been reported to complex with specific proteins (Fullington 1974). HPMC increases the viscosity of the food system at room temperature while remaining relatively inert (Anonymous 1996). HPMC probably does not interact either with starch or other additives (such as shortening) during processing. There is a need to explore other techniques which enable a whole-rice bread mix to retain gases during proofing and subsequent baking.

The 2θ peak intensities on XRD of fresh and 1-w-old refrigerated breads is shown in Table 4. Previous work (Kadan and others 2001) had shown that LG rice flour used to make rice breads had lost its characteristic 'A' pattern during extrusion-cooking and had acquired a 'V' pattern in cooked rice flour. The 2θ peak intensities of all 3 fresh breads also exhibited a typical 'V' pattern, indicating the well cooked nature of their starches. The 2θ peak intensities of well cooked LG rice flour were at 13.3° and 19.3° (Kadan and others 2001), whereas the peak intensities of the fresh rice breads were at 12.8° and 19.5°. The slight shift of the 2θ peaks and their diffused nature is probably due to the interaction of other ingredients with the amylose contents during processing. The 1-w-old retrograded rice breads developed new 2θ peaks between 16.7° and 17.0° and a decrease in their peak intensities at 19.5°. Retrograded wheat bread is known to develop a 'B' pattern (Zobel and Senti 1959). The peak intensity at 16.7° to 17.0° is characteristic of the 'B' pattern in starches (Hoseney 1994). 7-d-old whole-wheat bread showed a slight increase in peak intensity at 16.7° to 17.0° and 19.5°. Retrograded rice starch gels are reported to have peaks at 16.7° and 17.0° from waxy and non-waxy rices (Kim and others 1997). It can therefore be concluded that the appearances of 2θ peaks between 16.7° and 17.0° in rice breads is due to their starch retrogradation. Bread from LG retrogradation is also accompanied by a decrease in the 2θ peak at 19.3°. The incorporation of even small amounts of SG, which had no amylose contents (Kadan and others 2001), decreased the starch retrogradation in rice bread and therefore also decreased the 2θ peaks between 16.7° and 17.0°. The appearance of the 2θ peaks at 16.7° to 17.0° and at 19.5° in whole-wheat bread indicated that the bread was already "old," even though sold as fresh in the grocery store. It had already undergone considerable retrogradation which continued even further in 1-w storage.

The absence of commercial whole-rice bread even in specialty grocery stores, and recent reports of adding other ingredients such as potato starch (Ylimaki and others 1991), soybean (Moharram and others 1990), wheat flour (Noomhorm and Bandola 1994) and ispaghula husk (Haque and others 1994) to rice breads probably highlights the difficulty of making a good rice bread. The addition of other grain ingredients can also unnecessarily expose sensitive consumers to dangerous gluten-sensitivity reactions. On the other hand, the addition of defatted rice bran (a low-cost, underutilized, nutritious food product) provides a safe and nutritional characteristic to whole-rice bread. The reasons for decreases in specific volume of rice bread due to addition of rice bran are not clear. The fact that the addition of even small amounts (10%) of SG to LG rice flour improved the texture, and also slowed the retrogradation of rice breads, indicates the need for identifying an appropriate rice cultivar or combinations of two or more cultivars for rice bread application. Similarly, slight modification of rice proteins and fiber by the addition of enzymes during proofing might improve the hydrophilic properties and hence, the specific volume of the bread. Whole-rice bread does not necessarily have to be like whole-wheat bread, but the rice bread made by current techniques probably still does not meet the quality expectations of current potential consumers. Some retrogradation of rice bread during storage may not be that objectionable, as it imparts desirable hypoglycemic properties to bread (Kim and others 1997), provided it does meet the acceptable standards in flavor and texture.

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